

Brain-Computer Interface (BCI): a methodological proposal to assess the impacts of medical applications in 2022 ⁵

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Abstract

Technology assessment is essentially an approach, a collective of the systematic methods used to scientifically investigate the conditions for and the consequences of technology and technicising and to denote their societal evaluation. It is an investigation about the technological developments as well as an evaluation of its potential impacts on society. The assessment of emerging technologies, however, requires special attention. Brain-Computer Interface (BCI) is an emerging technology which allows for the direct communication between the brain and an external device. It is a truly direct connection, with no use of the normal output pathways of peripheral nerves and muscles, allowing for the brain to have control over objects and software without intermediates. To address these kinds of technologies at early stages of development, Constructive Technology Assessment (CTA), a member of Technology Assessment approaches, has been considered as one of the most fitting approaches. As an emerging technology, BCI is at its early stages of research and thus many challenges are still ahead. Mainstream adoption is not expected in least 10 years many challenges are yet to be overcome. Therefore, the objective of this article is to discuss and present a methodological approach to assess brain-computer interface technology considering constructive technology assessment and future oriented

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technology analysis as the main processes to undertake the assessment. The assessment will focus only on the non-invasive type of BCI and for medical applications in three defined areas: Communication & Control, Motor Substitution and Motor Recovery for a time horizon of 10 years, 2022. These areas were chosen based on the capability of BCI to serve as a replacement of normal neuromuscular pathways. That makes it one of the best technologies to help people in activating and controlling assistive technologies which enable communication and control of the environment. However, the real impacts of BCI will depend directly on the development of competing technologies, and also on the improvement in BCI research. Only then, the potential applications and end users could grow dramatically.

Key-Words: Technology Assessment; Constructive Technology Assessment; Emerging Technologies; Brain-Computer Interfaces; Brain-Machine Interfaces.

JEL codes: I18, M15, O33

Introduction

In current times information is available in an overwhelming volume, comes from multiple sources and brings new points of view and content every day. Daily, people are confronted with visionary ideas, some of them with the revolutionary potential for changing society. Several technologies and changes are pointing to such a radical change, such as genetic modification, brain manipulation, controlling computers with thoughts, the end of aging and/or death, among others. The pace and acceleration of the technological process is full of new discoveries, innovation, development and learning. It has been taking place in an unprecedented rate in the history of mankind. In a general way it can be said that a technological wave is now under course to revolutionize the world. One of such technologies is Brain-Computer Interfaces (BCI).

A BCI is a communication system in which messages of commands that an individual sends to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles (Wolpaw et al., 2002). Although theoretically BCIs are expected to be able to allow people to control many aspects of their surroundings, they still fall short of offering that in a practical and effective way. And there is no perspective for that happening in the near future (FBNCI Project, 2011). The fact is that the impacts and consequences of BCIs are still not clearly understood. Ethically, philosophically, morally or religiously speaking, many doubts have arisen concerning the potential for these technologies to change society.

The known fact is that the developments of bioengineering are slowly but surely blurring the limits between science, engineering and society, living and non-

living, sickness, health and improvements, technology and nature, as well as between human and machine intelligence. These changes have brought a discomfort to the society at large as they defy many of the basic concepts, which describe the understanding of the world, as well as to define what it means to be human (Making Perfect Life, 2011).

The brain has been considered as fundamental for the process of existence, once it is responsible for defining individualities and it is also the creator of the properties that defines humans. Research on the brain is a major topic in the beginning of this new century and BCI is one of these aforementioned new technologies that are believed to have the potential to bring a plethora of benefits. However, although it could, for instance, allow new human enhancements to be possible, it also raises important ethical and philosophical questions; discussions over the right to access other people's brains, read somebody else's minds, or get to know what someone is feeling, show us that such a technology creates, stimulates and opens new questions and doubts of great relevance. One alert that has arisen is that these technologies could even further emphasize and increase differences and distances already existing in the human society, creating new inequalities and more barriers between people.

These questions highlight the relevance of advancements in brain research and the importance of raising public awareness on the benefits and disadvantages yielded by it, as well as fostering a public debate on ethics and the philosophical and humanistic implications of such new discoveries allowing for choices to be made before the adoption of such technologies.

Given that some elements of the future will be profoundly different from those of the present, organizations must have a clear view on the theme, be it for discussing it or just adapting themselves, in order to attend to such issues and challenges as well as looking for seizing opportunities that will arise from this new strategic environment. Likewise, the main stakeholders and actors involved need to be made aware of this new situation, as well as should be prepared to act in such a different scientific and technological scenario. Thus, accepting that change is inevitable and that it could bring great benefit to society as a whole is paramount. To explore the main uncertainties and transition areas within this new strategic environment will help to define the conditions for a logical and disciplined transformation. This is of utmost importance to avoid being overwhelmed by the disruptive events as well as simply passively reacting to them. And the technology assessment is one of the main approaches to help them in this task.

Therefore, the objective of this article is to present a methodological approach to assess brain-computer interface technology considering constructive technology assessment and future oriented technology analysis as the main processes to undertake the assessment. In fact, Technology Assessment is primarily expected to supply information that enables people involved in decision-making about innovation to determine appropriate strategies (Boavida, 2011). Moreover, it is essential to discuss and reflect on the societal, ethical and philosophical aspects of technologies. This article then proposes a theoretical framework for an

analysis of the technology, pointing out the main challenges as well as the elaboration of future scenarios for it.

The role of Technology Assessment

Technology Assessment (TA) has been used in the European Union as a whole to assess emerging technologies such as BCI. Technology Assessment can be defined as "a scientific, interactive and communicative process, which aims to contribute to the formation of public and political opinion on societal aspects of science and technology", according to the European Parliamentary Technology Assessment Network - EPTA Network ⁶.

In fact, Banta (2009) says that, in the early years of TA studies, "technology assessment has been defined as a form of policy research that examines short and long term consequences (societal, economic, ethical, legal, etc) of the application of technology." Once again, the EPTA says, "Technology Assessment is a concept, which embraces different forms of policy analysis on the relation between science and technology on the one hand, and policy, society and the individual on the other hand". In general, the goal of technology assessment is to provide policy makers with information on policy alternatives.

The quote "TA started in the early 60's, as an "early warning" tool to inform parliaments about possible negative effects of new technologies" (Smits & Den Hertog, 1995) exemplifies this early and close connection between TA and the evaluation of possible impacts.

Grunwald states that TA "constitutes a scientific and societal response to problems in the interface between technology and society. TA is the most common collective designation of the systematic methods used to scientifically investigate the conditions for and the consequences of technology and technicising, and to denote their societal evaluation" (Grunwald, 2009). Moreover, he complements that TA "has emerged against the background of various experiences pertaining to the unintended and often undesirable side effects of science, technology and technicisation." And then concludes stating that in modern times, those side effects can assume extreme proportions.

According to the same author, the Technology Assessment approach is a result of an evolution coming from the following demands and challenges:

- The need of Integrating any available knowledge on the side effects in decision-making processes at an early stage;

⁶ <http://eptanetwork.org>

- The importance of supporting the evaluation of the value of technologies and their impacts;
- The need of elaborating strategies to deal with the knowledge uncertainties that inevitably arise;
- The relevance of contributing to the constructive solving of societal conflicts on technology and problems.

What characterizes TA is its specific combination of knowledge production (concerning the development, consequences and conditions for implementing technology), the evaluation of this knowledge from a societal perspective, and the recommendations made to politics and society. (Grunwald, 2009) All the various questions regarding TA concepts, methodology and content are linked to philosophy. On what concerns the normative questions that have a bearing on technological evaluation and technological design, there are close ethics of technology ties (Grunwald, 1999).

The European Parliamentary Technology Assessment Network and the The Science and Technology Options Assessment (STOA) ⁷ are two examples of TA in the European Union. The EPTA was formally established in 1990 under the patronage of the President of the European Parliament. The EPTA Partners advise parliaments on the possible social, economic and environmental impact of new sciences and technologies, while STOA is a resource for Committees of the European Parliament.

Many of the issues that come up before European governments have a scientific or technological dimension. Both technological and scientific advances are in the core of economic growth, and to understand how to support scientific and technological innovation as well as the impact of these technologies is of utmost importance. The reports prepared by the European Parliament Committees are the basis for the Parliament to define its position on such issues.

Moreover there are many other research groups/institutes working on TA, such as the Portuguese initiative GreAT ⁸ and the German institute ITAS ⁹. The latter researches scientific and technological developments concerning systemic relations and technology impacts with a focus on environmental, economic, social, and political-institutional questions.

⁷ <http://europarl.europa.eu/stoa/cms/home>

⁸ <http://avaliacaotecnologia.wordpress.com/>

⁹ <http://www.itas.kit.edu/>

Constructive Technology Assessment to assess Emerging Technologies

With the rapid pace of technological developments nowadays coupled with the high probability of new emerging technologies to cause breakthroughs and ruptures, the uncertainty that naturally permeates any debate about the present and especially the future is definitely increased.

These new emerging technologies have been described by (Harper, 2010) as ones that:

- Arise from new knowledge, or the innovative application of existing knowledge;
- Lead to the rapid development of new capabilities;
- Are projected to have significant systemic and long-lasting economic, social and political impacts;
- Create new opportunities for and challenges to addressing global issues; and,
- Have the potential to disrupt or create entire industries.

In the last decade, many authors and groups such as Halai, 2000; Gartner Group, 2011; MIT Technology Review, 2012¹⁰; FET Program, 2012¹¹ have been working on identifying this group of technologies and consider them as being of utmost importance for the future of mankind. However, such technologies are often subject of discussions and debates, especially from the ethical point of view, for although they may be able to bring benefits they could also be used for negative purposes. Supporters of technological change usually state that these technologies will contribute to improve the human condition while on the other hand critics of the risks of such changes point out the dangers that these technologies might represent, including existential risks.

In this sense, Brain-Computer Interface (BCI) or Brain-Machine Interface (BMI) is an emerging technology, at its initial stages of development. BCIs allow for direct communication between the brain and an external device. It functions as a

¹⁰ MIT Technology Review. Available in: <http://www2.technologyreview.com/tr10/>. Access in 20/08/2012.

¹¹ FET ICT – FUTURE AND EMERGING TECHNOLOGIES - is the ICT incubator and pathfinder for new ideas and themes for long-term research in the area of information and communication technologies. Its mission is to promote high risk research, offset by potential breakthrough with high technological or societal impact. Available in: http://cordis.europa.eu/fp7/ict/programme/fet_en.html. Access in 21/08/2012.

bridge connecting the two systems, thus permitting the control of software and hardware systems. It provides new and extended ways of interaction between humans and machines. With BCI, there is no use of the normal output pathways of peripheral nerves and muscles, allowing for the brain to have control over devices and softwares without intermediates.

In other words, a BCI system relies solely on mental activity to control a computer on an embedded system, which then controls a certain application for communication, transportation or any other need of the user. To achieve this, BCI systems use several techniques to differentiate among different mental tasks (Lebedev & Nicolelis, 2006; Donoghue, 2002; Cabrera, 2009; Mak & Wolpaw, 2009; Nicolas-Alonso & Gomez-Gil, 2012).

As an emerging technology, many challenges still lie ahead for BCI and its mainstream adoption will not come before at least 10 years, according to Gartner's Hype Cycle for Emerging Technologies (Gartner Group, 2011). For this reason, in this article, the Constructive Technology Assessment (CTA) approach is discussed as being the best approach to allow for an evaluation of potential impacts and current perspectives for BCIs. CTA is one member of a family of recently emerging TA approaches aimed at improving the understanding, evaluation and practice of technology development in its various aspects (Genus, 2006). It is considered to be one of the best options to bypass the Collingridge dilemma - which fundamentally states that controlling the direction of a technology's development is very hard because technologies at early stages of development there are many opportunities to steer to, creating a high level of uncertainty on future paths to take. On the other hand, technologies in later stages of development have but few opportunities to steer to, and might become more consolidated, crystallized, one could even say. Steering further developments of such technologies to specific directions is then rendered more difficult. (van Merkek & Smits, 2007). This bypass of the Collingridge dilemma is overcome by CTA by developing and testing scenarios, including options for the further development of those emerging technologies. (van Merkek & Smits, 2007)

The proposal of CTA is to do so anticipating potential impacts and providing feedback (insights) into decision makers and the stakeholders' strategies. CTA is viewed as "an active, positive form of shaping technological development in reaction to the original "early warning" approach" (Eijnhoven, 1997).

Furthermore, van Merkek & Smits (2007) discussed a process of tailoring CTA for emerging technologies and emphasize some CTA characteristics as well as interaction amongst stakeholders in order to assess this kind of technologies. Schot and Rip (1997) shows that one of the main characteristics of CTA is a commitment to the reduction of the costs of human trial and error learning on what concerns how society deals with new technologies. And Genus (2006) points out the main characteristics, considering the opinions of several authors. According to this, the main characteristics of CTA are:

- a) integration of anticipation of the future effects of technology into the

promotion and introduction of technology, meaning 'that actors involved in control activities should actively participate in the technology design and development practices';

- b) inclusion of more social actors and aspects of technology during development and introduction of technology 'in order to improve the quality of technology in society';
- c) that modulation ('change') processes should be seen as ongoing, enabling all actors to learn about 'the possible new linkages between the design options and the demands and preferences of the envisaged users'. Learning should 'include aspects of the political and social articulation of acceptability of technology in development and its linkages to broader cultural values in society';
- d) actors should be 'reflexive' about the processes of co-evolution of technology and society, of technology and its impacts'.

A central aspect here is the concept of responsible innovation. This notion implies a commitment to develop and use technology to help meet the most pressing human and social needs, while making every reasonable effort to anticipate and mitigate adverse implications or unintended consequences. Responsible innovation often not about innovation but about development of S&T. (Rip, 2011) In fact, Grunwald (2011) reinforces this concept when stating that responsible innovation adds explicit ethical reflection to Technology Assessment and science, technology and society studies and includes all of them into integrative approaches to shaping technology and innovation.

The role of BCIs

According to a report made by the European Space Agency (ESA) by Carpi & Rossi (2006), there is currently a great demand for BCIs which is arising. The promises of recent scientific and technological results encourage and foster the focusing of more efforts into this direction. The report states that "The possibility of measuring, processing and decoding brain activity, so that to interpret neuronal signals, is regarded as the challenging possibility of bypassing damaged neural and/or motor structures in patients affected by motor disorders and paralyses."

The Gartner Group Hype Cycle for Emerging Technologies in the year 2011 states that these systems provide new and extended ways of interaction between

humans and machines. According to several authors, Brain-computer interfaces (BCI), or brain-machine interfaces (BMI), are essentially systems designed to aid humans with central nervous system disabilities, including disabilities in movement, communication, and independent control of one's environment (Donoghue, 2002; Friebs et al., 2004; Lebedev & Nicolelis, 2006; Cabrera, 2009). These authors further add that a BCI system relies solely on mental activity to control a computer on an embedded system, which then controls a certain application for communication, transportation or any other need of the user. To achieve this, BCI systems use several techniques to differentiate among different mental tasks.

According to the FBNCI Project, 2011, in order to be considered a BCI, four criteria must be met. The device must rely on direct measures of brain activity, it must provide feedback to the user, must operate in real time and must rely on intentional control; the user chooses to perform a mental task, aiming at sending a command or message for each time the BCI is used.

Wolpaw (2002) defines four essential elements which are used by BCIs in order to provide this direct communication pathway: signal acquisition, feature extraction, feature translation and device output. Thus, brain signals are recorded, and then processed for extraction of features (spontaneous mental activities), which are then classified for proper translation into commands for the device or application. Mak & Wolpaw (2009) also state that the potential clinical uses of BCIs can be for direct control of assistive technologies and neurorehabilitation. And since the BCI serves as a replacement of normal neuromuscular pathways, the most obvious applications are those that activate and control assistive technologies that are already in place to enable communication and control of the environment. These applications to assistive technology encompass the areas of communication, movement control, environmental control, and locomotion. Then, this technology makes possible for humans to control prosthesis, wheelchairs, play videogames, write, between others tasks, only using the brain.

The first characteristic, which differentiates BCIs among themselves, is the method used for signal acquisition. It can be either invasive or non-invasive. BCIs which record signals from outside the skull are called non invasive and rely mostly on Electroencephalography or EEG. Invasive recorders on the other hand use neural signals obtained from within the skull, either from the surface of the brain cortex itself or even inside the brain (Birbaumer, N., 2006).

On Invasive BCIs, although the neural signals have the best quality, and therefore greater potential to have better results, they carry risks associated with invasive surgical procedures. On Non-Invasive BCIs, the neuro signals have a limited bandwidth, but carry no apparent risks in its implementation and reading of brain waves (Lebedev & Nicolelis, 2006).

The non-invasive methods have been successfully used in patients both partially or severely paralyzed, allowing them to have basic forms of communication and control in their interaction with the external world. However, in order to have a

better motor recovery, there is a need for brain signals with better resolution. The invasive methods have greatly improved brain signal resolution, but because of its surgical procedures, brain microchip implants and significant risks associated there is still much resistance against it. (Birbaumer & Cohen, 2007; Nicolas-Alonso & Gomez-Gil 2012).

There are other types of BCI, such as passive and hybrid, which combined with other technologies or with no intention from the users can also provide a direct communication and control of a computer system, using only the brain. However they do not fit the definition of BCIs as mentioned above.

Although BCIs have initially been conceived as a potential new therapy to restore motor control in severely disabled patients (particularly those suffering from devastating conditions as amyotrophic lateral sclerosis (ALS), spinal cord injury, stroke and cerebral palsy (Lebedev & Nicolelis, 2006; Wolpaw, 2007), current and future perspectives also include the development of BCIs in other areas and with different purposes, such as in entertainment, and also to improve human performance, as covered by the Human Enhancement Report (Coenen et al, 2009).

Among other perspectives for the future, the WTEC study (Berger et al.; 2007) identifies the following opportunities for multidisciplinary BCI teams to find transformational solutions:

- Studying multiple levels and multiple scales of neural functions and neural code;
- Developing long-term biocompatibility between electronics and neural tissues;
- Establishing bidirectional communication between bio-mimetic devices and the nervous system;
- Developing hierarchically organized control systems for robotics and bio-mimetics;
- Developing biologically inspired systems that will push the frontier for the development of autonomous intelligent systems ("conscious" self-adaptive systems);
- Engineering practical BCIs and even integrating BCIs with cyber-infrastructure.

The applications of BCI are also varied. Among the current application areas are Health related applications (Assistive technologies, such as monitoring, therapy, diagnostics and wellness), Entertainment (art and games), Defense (military and forensics), Human Computer Interaction (new interfaces, situational disability), Educational (Serious games), Finance (Neuro-economy and neuro-marketing)

and Nutrition. Among the most promising ones are assistive technologies and gaming (FBNCI Project; 2011).

Although the BCI field is very large and encompasses many different areas of applications, the most advanced research available at the moment is found within the medical applications area, which has also been a very important driving factor in development of the technology.

Main issues and questions to be assessed

This article discusses and presents which would be the best approach and methodology to assess a particular set of BCI medical applications, Communication & Control, Motor Recovery and Motor Substitution. Why choose medical applications and why these specific three ones?

The TOBI project (Tools for Brain-Computer Interaction), a large European integrated project which will develop practical technology for brain-computer interaction (BCI) that will improve the quality of life of disabled people and the effectiveness of rehabilitation ¹² aims at designing non-invasive BCI prototypes that will be combined with existing assistive technologies and rehabilitation protocols. This project is expected to have an impact by broadening the appropriate use of BCI assistive technology, by incorporating adaptive capabilities that augment those other assistive technologies they are combined with. According to this, the main application areas where BCI assistive technology can make a real impact for people with motor disabilities are: Communication & Control; Motor Substitution; Entertainment; and Motor Recovery.

But exactly what type of assistance can Brain Computer Interfaces really provide people with disabilities? Millán et al (2010) state that despite progress in assistive technologies, there is still a large number of people with severe motor disabilities who cannot fully benefit from them and BCI could be a solution for them. However, although BCI has advanced a great deal in the years of research put into it, Millán, J. d. R. et al. (2010) also say that today's state-of-the-art shows "BCI alone cannot make patients interact with and control assistive devices over long periods of time and without expert assistance".

As mentioned, this article proposes to present a methodological reference to assess the impacts of BCI in 2022, focused on non invasive EEG based medical applications, namely Communication & Control, Motor Substitution and Motor Control. The three medical application of BCI assessed here are:

¹² <http://www.tobi-project.org/>

- *Communication/control*, for people unable to communicate with the outside world and have no control to perform any tasks whatsoever via other existing methods, such as in the locked-in syndrome cases;
- *Motor recovery*, for users who lost their ability to move a part of their body, but still have physical capacities to do so, and need to relearn how to do it;
- *Motor substitution*, for people who have lost the capacity to receive sensory stimuli from parts of their bodies in order to react to these feedbacks properly, whereas BCI comes in to substitute this original signal transduction pathway or sensory stimuli. Those are very prominent areas as of now.

All three of them are in more advanced stages when compared to other applications of BCI within the medical area. There is however controversy as if BCI alone will be able to fulfill its potential or if it will need to be combined with other technology in order to better help people. Hybrid BCIs could be an answer to that. But why these three specific medical applications?

Non-invasive BCI for Communication and Control

The Braingate project ¹³ states that for people with locked-in syndrome, due to brainstem injury, ALS or other reasons, restoration of easy communication is a priority. The utilization of slow cortical potentials to control a computer-aided spelling system as mentioned by Nicoletis & Lebedev (2002) is an example of how communication and control go together with good results so far. BCI can thus provide an alternative method of communication and control for those severely affected individuals (Wolpaw, 2002).

Many communication and control applications for BCI have been designed to demonstrate proof of principle. According to T. W. Berger et al. (2007), several features from BCI serve as a basis for this, namely: slow cortical potentials, motor potentials, event-related synchronizations & de-synchronizations, steady-state evoked potentials and P300 potentials.

Once more, Berger, T. W. et al. (2007) state that the population of potential users of BCI communication devices will mostly depend on the communication rates that can be realized as well as how easy will it be to use these systems. Current BCI communication devices have only acceptable communication rates, with not

¹³ <http://www.braingate2.org/>

many other options, rendering the expansion of the potential user base depending directly upon advances that result in increased rates and accuracy.

Developments of practical BCI communication systems face mainly two issues. A) The limited bandwidth of current systems and b) the technical difficulty existing in the use of current-generation systems. "There are individuals and their caregivers who are willing and able to deal with these problems." To Increase the bandwidth of BCI communication systems, it depends directly on the continuing innovative exploration of new methods and signals, as well as a more profound understanding of the phenomena to which these methods are applied. "To reduce the technical complexity of current BCI communication systems is a matter of applying existing technology". Berger et al (2007).

Non-invasive BCI for Motor Substitution

According to the Human Enhancement Report (2009), although there is much fast progress in BCIs that allow for motor substitution and even motor recovery, the applications are still only therapeutic and do not offer advantages over "non enhanced" humans, once that the level of improvement of functions is still way below the level of normal function.

On the other side, for the TOBI project, the possibility to restore lost motor functions is a priority for people with physical disabilities, roughly classified as manipulation and mobility. One of the aims of this project is the development of neuro-prostheses for grasping and reaching, as well as of assistive mobility – as of now, operation of hand, as in grasping and the elbow, for reaching are in development by the project. Another aims is to develop tele-presence enabled mobile robot with a camera and a screen that can be mentally driven, so users can to join their relatives and friends located somewhere else and participate in their activities. Still in accordance with the project, although advanced prosthetic limbs have improved a great deal in recent times and are at a high level of development, they require better controllers. The project's hypothesis is that using the brain signals directly related to intend movement of the hand will enable easier and more complex control over these prosthetic limbs than what currently exists.

In focus for the TOBI project is the direct improvement of motor functions or the provision of alternative methods for their substitution in severely physical disabled persons. Because current technologies can only restore grasping function in case of missing surgical options are only applicable if shoulder and elbow functions are preserved to a large extent. The project mentions several

works on BCI for motor substitution, namely Hybrid-Brain Computer Interface (h-BCI), Telepresence Robot, Controlling an Artificial Arm with BCI, FES Hand Orthosis for Long-term Use, h-BCI Controlled Arm FES-Orthosis and Multitasking: Writing with a BCI-FES Orthosis.

The Braingate project has also mentioned Motor Substitution applications. According to this, one approach is to provide improved control for people with cervical spinal cord injury or brainstem stroke, where the signals from the motor cortex have been “disconnected” from the limb, would be safe and useful robotic limbs, attached to a wheelchair and used much in the same way the arm and hand was used prior to injury to the nervous system.

Non-invasive BCI for Motor Recovery

The Braingate project states that the real “dream” for technology is to reconnect brain-to-limb and now they are currently developing systems that aim at allowing people with paralysis to reanimate their own limbs by thinking about moving them, using BCI. One long-term goal of such kind of research, on Motor Recovery, is to enable quadriplegics to control their own limbs via electrical stimulation of their muscles (cf. Bieber 2006).

To the TOBI project, on the other hand, using Hybrid BCIs during functional motor recovery after stroke and, thus to enhance those physiological plasticity phenomena which are the substrate for functional motor recovery itself. Prototypes have been designed to be combined with existing assistive technologies and rehabilitation protocols, where users can couple brain interaction with muscle-based interaction or switch between the different ways of interacting in a natural way. The project states that one of its goals is to exploit BCI training paradigm as a behavioral, controlled strategy in order to recruit and/or reinforce patient's sensorimotor experience (like motor imagery and residual motor ability).

According to the Brainable project ¹⁴ the idea is to give some autonomy and social inclusion through mixed reality Brain-Computer Interfaces by connecting the disabled to their physical and social world. The project aims to research, design, implement and validate an ICT-based HCI (Human Computer Interface) composed of BNCI (Brain Neural Computer Interface) sensors combined with affective computing and virtual environments.

The scope of the article is restricted to the three medical applications mentioned with non invasive EEG as the tool for capturing the brain signals. It is the best option because non invasive EEG is considered a convenient, safe, and

¹⁴ <http://www.brainable.org/>

inexpensive recording method that is ideal to bring BCI technology to a large population. Millán, Tobin et al (2011)

The TOBI Project states that "in recent years, new research has brought the field of EEG-based Brain-Computer Interfacing (BCI) out of its infancy and into a phase of relative maturity through many demonstrated prototypes such as brain-controlled wheelchairs, keyboards, and computer games. BCI technology is dominated by deriving useful EEG control signals." Wolpaw et al. 2002, also state that many studies have shown that EEG could be used as the basis for a brain-computer interface because EEG recordings provide a safe alternative to invasive methods that may provide useful BCI communication devices for individuals with disabilities.

The report "Non invasive brain-machine interfaces" performed by the Interdepartmental Research Center "E. Piaggio" of the University of Pisa within the ARIADNA framework of activities promoted by the European Space Agency (ESA) states into the direction of EEG for BCIs. "The most studied potential interface for BCI has been EEG, mainly due to its fine temporal resolution, ease of use, portability, and cost of set-up. However, practical use of EEG as a BCI requires a great deal of user training and is highly susceptible to noise."

The EEG BCI approach has been tested and proved useful in helping paralyzed or 'locked in' patients to develop ways of communication with the external world and have been implemented as solutions for patients suffering from various degrees of body paralysis. These BCIs enable control of computer cursors, which the patients use to communicate with the external world or to indicate their intentions and the first successful and most well received application of such an approach was based on the utilization of slow cortical potentials to control a computer-aided spelling system (Nicolelis, Lebedev, 2002).

However widespread clinical application of EEG based BCIs has not yet been seen. Due to the nature of the EEG signal acquisition (the synchronous activity of thousands of cortical neurons), EEG have a reduced spatial resolution, and because of their placement, on the scalp, they are susceptible to artifacts generated by muscle contractions and ocular movements, as well as outside sources. That currently limits the EEG based BCIs to low information transfer rates, which renders it to be considered too slow to control complex devices. The answer to if EEG is the ultimate signal for BCIs remains open, nevertheless. Decoding techniques that involve mutual learning (or co-adaptation) between users and BCIs are helping with these problems of low information transfer rates, limited spatial resolution and the high susceptibility to noise interference. (Millán et al., 2010) That also shows that there are still many technological challenges to be overcome as well as hints at the possibility of different solutions being found in the next years to come.

In contrast to invasive systems, noninvasive BCI systems are currently at a point in their development where they could provide the most severely motor-impaired individuals with an alternative means of communication. The WTEC Panel report, Berger et al (2007) mention that a P300-based system has already been

installed in the home of a 47-year old man with ALS. The report also states that this user used the device in average 4 to 6 hours per day for tasks such as using email and that he found the BCI system to be superior to an eye-gaze system he had been using before.

Once the technological developments of this combination (BCI, Non Invasive, EEG) are in more advanced stages than others (although still very early stages themselves) solutions that arise for it may be of use to any other BCI applications, even if they are invasive. In addition, Millán et al. (2010) points that recent progress in BCI seems to indicate that time is ripe for developing practical technology for brain-computer interaction; it means that BCI prototypes combined with other assistive technologies will have a real impact in improving the quality of life of disabled people. This is particularly the case for the application areas already presented above: Motor Substitution; Communication and Control, and Motor Recovery.

There are still many challenges these applications will have to face - to understand the main technological challenges, what is already in development and possible prototyping already in use, and understand these technical challenges is of utmost importance in order to realize how can the development of these applications help the end users, and further define who they are going to be as well as the ethical, normative and political questions associated with the adoption of such technologies and applications.

If the challenges for these three specific areas are overcome, such as faster and more accurate feedback for communication/control applications, higher degrees of freedom for prosthesis and more accuracy in moving and grasping objects, as well as more feeling feedback for the patients, then new possibilities can arise for the medical area. The most benefits will come to patients/users, not only those willing to be able to communicate with the world again, after being "locked in" their own bodies, up to those wishing to regain a normal life. Moreover there are those interested in obtaining full recovery enough to be placed in the workforce again. These technologies will indeed have a high impact on those groups of people.

However, ethical questions, of normative nature as well as the management of markets on using such technologies, remain open. It is important to go deeper into these ethical questions related to research and development, as well as further understand how will the diverse associations (research, social, human rights, privacy, etc) react to such developments. In addition to these questions it's of utmost important to discuss about the philosophical questions based on the universal rights of the human being, as well as the definition of what is a human being and its positioning on this planet.

The idea is to consider the following question as a starting point: *"What will be the social impacts, as well as perspectives of EEG based BCI medical applications for communication/control, motor recovery and motor substitution within Europe in 2022?"* Reflecting upon this question, other main issues are raised:

- Who will be in charge of the standardization of such technologies? Governments? Parliaments? Industrial Associations? Standard and Norms Institutes?
- And who will be the diffusing market of such technologies? What is going to be the role of the medical associations, hospitals and users/patients? What kind of networks will form or be consolidated around such applications? In which way the users/patients will have an active role in the definition and decisions concerning the social and technological context of such applications?
- Who will be the end-users/patients of such technologies? And how should they be addressed? User? End-user? Patient? What's the scope of users?
- Who will be the people responsible for taking care of these end users of the technology, assisting them in the processes of actively using and benefiting from the technology?
- What could be the benefits as well as setbacks for the users hailing from BCIs in 2022?
- Are BCIs become a major character in the interactions among users and their environment or will it become merely a supporting character in assisting the improvement of such interactions in 2022?
- Will BCI overcome its current challenges and limitations and have more utility for its end users/patients in 10 years?
- How will governments, the industry and society face the ethical and legal issues brought up by BCIs and will they be able to address these issues in a timely fashion?
- How will institutes; companies and governments interact in development of BCIs given their relevance within the different application areas?
- Given that funding is and will remain a fundamental point in the development of BCIs what are going to be the main sources of investment to its development?
- Will the development of BCIs shift the perception that society has of itself as well as the perception of what does a human being is?
- What social implications can rise of these different perceptions?

There are relevant impacts within our society that could arise from BCI's. The suggested approach to these questions is conveyed within the framework of CTA, through which it is believed that an effective, comprehensive, thorough and objective assessment of the technology can be made. It encompasses methods,

which are focused on interaction, creativity, expertise and evidence as well as are considered qualitative and semi-quantitative (Popper, 2008). Then, the chosen methods that will be used for this research are Literature Review/State of The Art, STEEPV, SWOT and additionally Interviews and Surveys. Scenarios will be made in the end, with a time horizon of 2022.

An outline of the methodological approach

This kind of research, which analyzes emerging technologies aims at creating a clear and defined framework to the research question. It also aims at presenting future possibilities for the technologies, given that their real applicability and development is feasible and useful, as well as its results are relevant to a certain social group. Likewise, it aims at understanding the positive and negative impacts which might arise from the introduction of such technologies into society, from the point of view of end users as well as the core concepts being human, and the basis of the society in which we live in.

In order to perform a careful, detailed and criterious assessment, and obtain the best results, reasonable limits need to be established. The strategic focus, time horizon and scope must be defined, as well as the selection of stakeholders to be consulted and the methods and techniques to be used in this approach must be well defined and justified, by scientific and innovative relevance.

- The strategic focus is Non-Invasive BCI using EEG for three specific medical applications, namely Motor Substitution, Motor Recovery and Communication/Control. By being Non-invasive and used with for medical applications it involves a high number of stakeholders. It is also one of the combinations (Non-Invasive and these three medical applications) which gathers the most technologically advanced applications. This allows an easier access to information, which is crucial for the process of Constructive Technology Assessment.
- Based on the Hype Cycle for Emerging Technologies report published by The Gartner Group, BCIs are not expected to reach mainstream adoption in less than 10 years. Both the reports from 2010 and 2011 have confirmed the same findings. Thus, the time horizon for this research has been set to 10 years. Therefore, impacts will be analyzed with the year of 2022 in mind.
- The Scope is the European Union. In the early stages of this research a

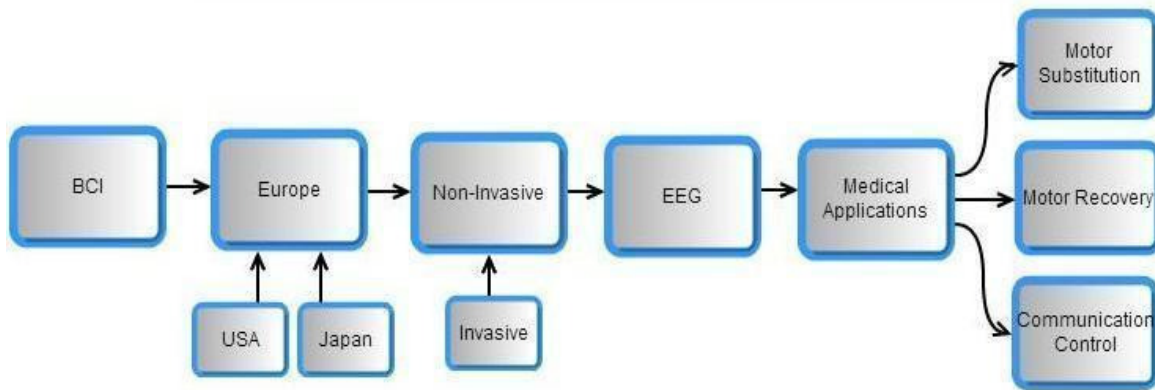
selection of stakeholders will be done. The timeframe of the project, as well as a clearer definition of the methods and techniques to be applied will be undertaken.

The scope of the research was chosen based on current trends of BCI research now in expansion all around the world. Relevant and important research in BCI is being conducted in the USA, Europe, Japan, among others, developing not only the hardware itself (the equipment that actually measures brain activity) as well as softwares used to operate it, in the academic and industry environments. For this reason, this study will collect, systematize and analyze BCI related information within North America, Europe and Japan. The technological roadmap elaborated by the FBNCI Project is one report which shows that most of the stakeholders involved with BCI come from these three regions.

In order to fully understand the technologies and its challenges it is needed to address researchers, institutes, universities, R&D, industries, as well as clinics, hospitals, and other places where the technology will be put to use. It will be required to search for an understanding of the scientific universe and the challenges, the point of view of the philosophers, ethic researchers, people in charge of norms and standards in order to listen to their point of views regarding what has been mapped with the first groups and its studies. Likewise, it's needed to search for people within the government/parliament who would be interested in discussing such topics and observe which opinions and point of views might arise from those, regarding the present situation as well as the different possibilities of the technologies at hand.

Given this time horizon, and the very nature of emerging technologies, a combined approach of CTA and Future Oriented Technology Analysis (FTA) has risen as a good opportunity to address the issues forthcoming. CTA aims to produce better technology in a better society, and emphasizes the early involvement of a broad array of actors to facilitate social learning about technology and potential impacts (Genus, 2006). FTA represents any systematic process to produce judgments about the characteristics of emerging technologies, its development pathways, and potential future impacts. Moreover, Technology Assessment is considered to be one of three subjects, which form the umbrella concept of FTA (Cagnin et al., 2008).

Last but not least, to narrow down the scope even further, the impacts of the technology will be assessed within the European environment; not only is this study being carried out in Europe but also there is a significant investment on the European Union part for research in BCIs and the discussion of its impacts in society as a whole. The figure below shows the definition of the Strategic Focus and the Scope.

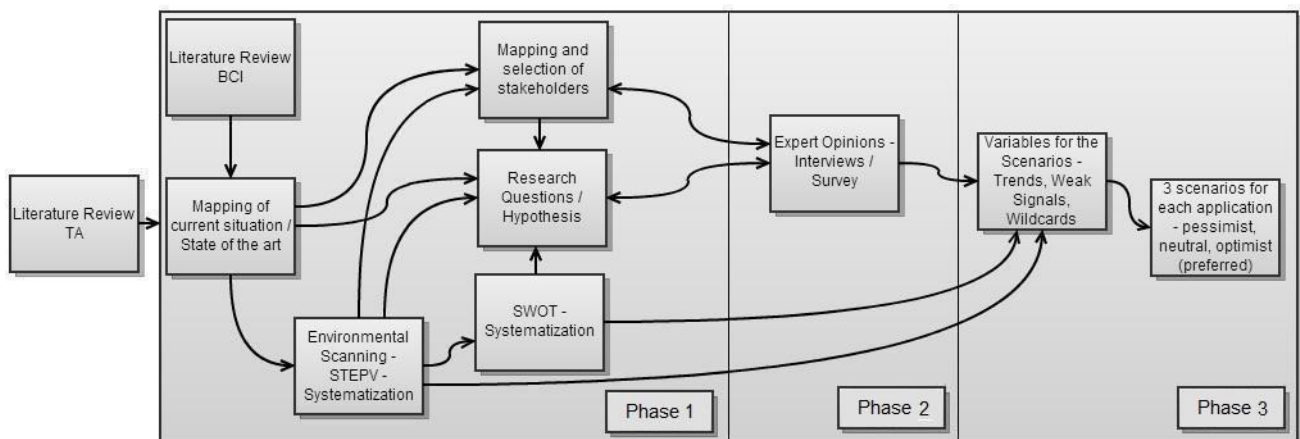
Figure 1 – Strategic Focus and Scope definition.

The proposed methodological structure has 3 phases: the first phase identifies the state of the art, systematizes information from the STEPV and SWOT methods, as well as the mapping of stakeholders to assist the research questions. In the second phase, the surveys are created from the research questions with information collected in the stakeholder mapping. Surveys are then sent and interviews with stakeholders from all areas are conducted. The results give feedback to the research questions as well as feed the next phase. The third phase constitutes the gathering of information for the creation of the scenarios, such as trends, weak signals, “wild cards” and is also fed by the SWOT, STEEPV (Social, Technological, Economic, Environmental, Political and Cultural Values) and Literature Review.

After that, the main idea is to develop 3 exploratory scenarios for each individual application of BCI aiming at a better understanding of some alternatives for the future. It is important to remember that all scenarios are possible and that amongst them there are the desirable and the probable, which may or may not be the same. Scenarios are stories or maps, if you will, of the future. Internally consistent, they have to describe pathways from the present to a horizon in a defined moment in the future. Good scenarios have their roots both in the past and in the present. They are a result of the interpretation of present and past events which are projected into the future. Scenarios focus on uncertainty.

The aim is to identify the largest number possible of uncertainties which might affect strategic decisions for organizations and governments. It makes possible the visualization of how decisions made today can have a relevant and confirmed impact against uncertainty in the future. The last phase aims at analyzing the results from the scenarios, defining recommendations and making considerations about the current and future states of the technology. The figure below, presents the proposed methodology, its phases as well as the development schedule.

Figure 2: Methodology and development schedule. Source: Own elaboration.



The proposed structure is as follows:

- To undertake a broad literature review of the theme in order to further understand the actual situation and its perspectives as well as to map the technological possibilities in the horizon and which applications are expected to surface;
- To structure and characterize the technology and identify which are the main issues associated with it, the aspects not fully understood at the moment as well as structure the methodology for the collection of the opinion of experts on a diversity of methods;
- Map strengths, weaknesses, opportunities and threats as well as define the social, technological, economical and ethical/cultural/philosophical limits related to the theme, drawing from the identified elements in the literature review;
- To map all the stakeholders involved with the technology in institutions, organizations, universities, private and public companies, the governments, experts, researchers to have a broad picture of the environment and later on select stakeholders for the consultations.
- To undertake consultations, interviews (defining the role of the experts, from scientific institutions, industry, economics, sociology and philosophy) and to

list the remaining information collection activities, systematizing the collected information and structuring the found results;

- To present the analysis and recommendations arising from the process. It is expected that the results of this project will be able to help the scientific, political and public communities to better understand Brain Computer Interfaces and how to take the best from it.

Final Remarks

Therefore, the main motivation for a research like this lies in the need to obtain a clearer view of this new context aiming at the creation of a well-structured framework to better support researchers of the area in the anticipation of future uncertainties aiming at a better handling of the impacts of new and revolutionary technologies such as BCI. The results of this research will be important considering:

Anticipatory planning: In situations of radical and accelerating technological change, very often crisis or the identification of potential threats and opportunities take place. Under such circumstances, previous planning might not be enough. Therefore, decision makers and policy makers need to be aware and alert to build the future instead of drifting between the uncertainties, oscillations and rules of the financial and economic markets. In this case, awareness must be increased as well as technological policies need to shift to better directions.

Competitiveness Analysis: the accurate examination of the driving factors directing the technology and its impacts in science, technology and society is an element of competitiveness. The knowledge of the competitiveness elements is an important factor that can be used to assist countries and regions in the pursuit for global leadership in a world of radical technological, social and economic shifts.

Opportunities: The opportunities and challenges brought by this new technological revolution will depend mostly on information, knowledge and expertise. The need to spread awareness as well as the need for clarity, comprehensiveness and relevance is of utmost importance.

Change Management: The management of such a fast and complex change is a challenge to businesses, organizations and people, as well as a challenge with relevant impacts to nations. The issues brought up by this change, regardless of nature, political, social or economic, must be addressed, discussed and understood.

The idea is to disseminate the results of this kind of research and the strategies

of communication of the findings will depend on the particular groups to be addressed. Possible paths could be:

- Professional associations
- Industry (Pharmaceutical societies, companies involved with BCI, etc);
- Researchers (advice on future directions - further interaction with other stakeholders (for cooperative work, funding, and other purposes)
- Information to the public, including citizens' movements.

On the other hand, politicians and moral organizations such as church could also be possible targets of the dissemination of the work in order to make this process as democratic and constructive as possible.

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